SUMMARY

The work summarized in this report has focused on the reduction of selenium from the selenate state to selenite or elemental state through a number of biological processes and process trains.

The four first-stage processes achieved soluble selenium reduction between 47 percent and 55 percent and the two second-stage processes reduced SSE between 41 percent and 87 percent. The lowest soluble selenium concentration achieved was 68 ug/L and that was for Train 1, UASBR>FBR1>SSF1. Even though none of the processes or trains reduced selenium to the target Water Quality Objective of 5 ug/L concentration as established by the State of California's Central Valley Regional Board for the San Joaquin Basin, the report has identified where additional work is needed to further develop the processes and trains in which they may be applicable for a specific role in the reduction and removal of selenium from agricultural drainage water.

The major overall operation problems encountered included precipitation of salt in piping and process units, attached biological growth in the piping and process units, and consistent and uniform operation of the chemical injection systems. The precipitation and growth are chemical and biological issues and are complex and more difficult to address than the mechanical issues of chemical injection systems.

Most of the time and effort at the Adams facility was spent on the development of the UASBR process. Reactor design and configuration play significant roles in the treatment efficiency of the process and is shown by comparing the results of the main and pilot-scale UASBRs.

Throughout the entire testing period, the pilot UASBR had reduced soluble selenium marginally better, but with considerably less retention time than that of the main unit. Both units had similar problems with sludge agglomeration and maintaining an evenly distributed flow through the reactor. Operation parameters were more easily controlled on the pilot unit due to its size and configuration, and results of some changes could be visually observed. For the main UASBR, recycle was used as a means to continuously mix and suspend the sludge bed, to prevent sludge agglomeration, and to distribute an even flow through the reactor. As a result, the main UASBR's operation was that of a completely mixed system, whereas the pilot UASBR's operation was that of a plug flow system. Upflow velocity for the main UASBR was 1.82 gpm/ft2 during Period 1 operations. During Period 3 operations, the upflow velocity range between 0.212 gpm/ft^2 and 0.433 gpm/ft^2 of which recycle was a major component except for a 7-month period from July 14, 1994 through February 13, 1995 when the main UASBR was operated without recycle. The recycle to influent flow ratio averaged 45:1 for Period 1 and ranged from 1:1 to beyond 90:1 when the main reactor was operated with recycle during period 3. From June 1, 1994 (commencement date for pilot UASBR's lab analyses), the pilot UASBR was operated without recycle and upflow velocity ranged between 0.202 gpm/ft2 and 0.442 gpm/ft2. Through trial and error, the method developed to agitate and mix the sludge bed and prevent sludge agglomeration in the pilot unit was to pulse flow through the pilot unit daily for 20 minutes using the recycle system. Twice during the test period, recycle was initiated as a means to continuously mix and agitate the sludge bed and to prevent sludge agglomeration in the pilot UASBR, but was terminated because an observed reduction in the size of the sludge

granules. Also, biomass production was observed in the pilot UASBR operations. Sludge had to be removed from the pilot unit on four occasions to improve operation.

The fluidized bed reactor process was used for both first- and second-stage treatment. Both reactors experienced problems with distribution of flow through the unit that were attributed to manifold design and attached biological growth. As a result, numerous modifications were made to both of their influent manifolds. Carryover of biomass from the main UASBR contributed to the distribution problem in FBR1. Both systems experienced biological growth on the interior of the piping and reactors and needed to be periodically cleaned. FBR2, being a first-stage process, experienced chemical precipitation in the system.

Slow sand filtration was used for both second- and third-stage treatment. The purpose for slow sand filtration was as a simple, low-cost, final polishing step to remove particulate selenium. Not only did the filters remove particulate selenium, but they also provided additional reduction of selenate and selenite and removed a portion of the biomass carryover from the upstream process. The filters required frequent backwashing. The filters also have flow distribution problems due to the biomass carryover and from salt precipitation and biological growth on both systems' interior walls. As a result, filter operations were labor intensive.

The packed bed reactor was the simplest to operate and required the least attention of all the processes tested. The PBR had problems identical to the other first-stage processes with biomass growth and precipitation in the system. The system, like the other processes, required periodic cleaning.

For the processes and treatment trains tested, selenium reduction was precedent upon the absence of nitrogen. The cost of the carbon to denitrify the drainage water is a key parameter in the economics of the processes. Methanol represented 21 percent and 31 percent of operation costs for 1- and 10-mgd plants, respectively, as reported by Owens in the 1995 operation report (ECSRI). Using IC laboratory nitrate analyses results, field dissolved oxygen measurements, and assuming the nitrite concentration to be zero, the cost for methanol (at $1.35 per gallon) required to deoxygenate and denitrify the drainage water is $95 per acre-foot. Except for the FBR2 during a 2-month period at the beginning operations, all first-stage processes were fed excess methanol. The cost for methanol ranged between $135 to $260 per acre-foot for the band of dosages tested at the Adams facility.

Molasses was tested as an alternative, low-cost carbon source using a small-scale UASBR (2.3 gallons) at the Adams facility. As reported by Owens (ECSRI 1998), molasses was less efficient than methanol in reducing nitrate and selenate due to a shift of bacteria from respiratory organisms to fermentative ones in the molasses-fed reactor as result of the high sugar content of the molasses. In anaerobic fermentation, the carbon source serves as both the electron acceptor and the electron donor, where as in anaerobic respiration, the carbon source serves only as an electron donor. For nitrate and selenate reduction to occur, anaerobic respiration must take place in which the carbon source only serves as the electron donor and the nitrate and selenate serve as the electron acceptor. This investigation showed reduction decreased as testing progressed. Coagulation and adsorption of selenium using ferric chloride also was investigated to determine the removal of particulate selenium and to investigate the adsorption of soluble selenium. This standard jar test investigation was performed on the effluents of the main UASBR, FBR1, and the UA2. The jar tests consisted of adding ferric chloride in varying amounts to 500 ml of effluent in a 1-liter beaker. The solution was rapid mixed, flocculated and then allowed to settle for a specific period of time. A portion of the supernatant was withdrawn from the beaker and analyzed for selenium. For the test using the UASBR effluent, $FeCl_3$ dosing ranged between 0 and 500 mg/L as Fe. Highest removal for total selenium, particulate selenium, and selenate were 32 %, 80 %, and 40 % at dosages of 50, 500, and 5mg/L as Fe, respectively. No significant reduction of soluble selenium was achieved. For the tests using UA2 effluent, highest removals occurred at the $FeCl_3$ dosage of 100 mg/L as Fe and were 37 % for total selenium, 34 % for soluble selenium, 44 % for particulate selenium, and lastly, 90 % for selenite. For the tests using FBR1 effluent, the highest removal for total selenium, particulate selenium, soluble selenium, and selenite were 71 %, 59 %, 95 %, and 91 % at $FeCl_3$ dosages of 250, 250, 500, and 50 mg/L as Fe, respectively. A second set of tests using the FBR1's effluent were performed. For these tests, only two dosages were used, 50 and 100 mg/L as Fe, at three flocculation durations which were 20, 30, and 40 minutes. The results showed relatively little difference in selenium removal for the parameters selected.